

1. Introduction

This report presents estimates by the United States government of U.S. anthropogenic greenhouse gas emissions and sinks for the years 1990 through 1999. A summary of these estimates is provided in Table 1-4 and Table 1-5 by gas and source category. The emission estimates in these tables are presented on both a full molecular mass basis and on a Global Warming Potential (GWP) weighted basis in order to show the relative contribution of each gas to global average radiative forcing.^{1,2} This report also discusses the methods and data used to calculate these emission estimates.

In June of 1992, the United States signed, and later ratified in October, the United Nations Framework Convention on Climate Change (UNFCCC). The objective of the UNFCCC is “to achieve...stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system.”^{3,4}

Parties to the Convention, by signing, make commitments “to develop, periodically update, publish and make available...national inventories of anthropogenic emissions by sources and removals by sinks of all greenhouse gases not controlled by the Montreal Protocol, using comparable methodologies...”⁵ The United States views this report as an opportunity to fulfill this commitment under UNFCCC.

In 1988, preceding the creation of the UNFCCC, the Intergovernmental Panel on Climate Change (IPCC) was jointly established by the World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP). The charter of the IPCC is to assess available scientific information on climate change, assess the environmental and socioeconomic impacts of climate change, and formulate response strategies (IPCC 1996). Under Working Group 1 of the IPCC, nearly 140 scientists and national experts from more than thirty countries collaborated in the creation of the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC/UNEP/OECD/IEA 1997) to ensure that the emission inventories submitted to the UNFCCC are consistent and comparable between nations. The *Revised 1996 IPCC Guidelines* were accepted by the IPCC at its Twelfth Session (Mexico City, 11-13 September 1996). The information provided in

¹ See the section below entitled *Global Warming Potentials* for an explanation of GWP values.

² See the section below entitled *What is Climate Change?* for an explanation of radiative forcing.

³ The term “anthropogenic”, in this context, refers to greenhouse gas emissions and removals that are a direct result of human activities or are the result of natural processes that have been affected by human activities (IPCC/UNEP/OECD/IEA 1997).

⁴ Article 2 of the Framework Convention on Climate Change published by the UNEP/WMO Information Unit on Climate Change. See <<http://www.unfccc.de>>. (UNEP/WMO 2000)

⁵ Article 4 of the Framework Convention on Climate Change published by the UNEP/WMO Information Unit on Climate Change (also identified in Article 12). See <<http://www.unfccc.de>>. (UNEP/WMO 2000)

this inventory is presented in accordance with these guidelines. Additionally, in order to fully comply with the *Revised 1996 IPCC Guidelines*, the United States has provided estimates of carbon dioxide emissions from fossil fuel combustion using the IPCC Reference Approach in Annex R.

Overall, the purpose of an inventory of anthropogenic greenhouse gas emissions is (1) to provide a basis for the ongoing development of methodologies for estimating sources and sinks of greenhouse gases; (2) to provide a common and consistent mechanism through which Parties to the UNFCCC can estimate emissions and compare the relative contribution of individual sources, gases, and nations to climate change; and (3) as a prerequisite for accounting for reductions and evaluating possible mitigation strategies.

What is Climate Change?

Climate change refers to long-term fluctuations in temperature, precipitation, wind, and other elements of the Earth's climate system.⁶ Natural processes such as solar-irradiance variations, variations in the Earth's orbital parameters,⁷ and volcanic activity can produce variations in climate. The climate system can also be influenced by changes in the concentration of various gases in the atmosphere, which affect the Earth's absorption of radiation.

The Earth naturally absorbs and reflects incoming solar radiation and emits longer wavelength terrestrial (thermal) radiation back into space. On average, the absorbed solar radiation is balanced by the outgoing terrestrial radiation emitted to space. A portion of this terrestrial radiation, though, is itself absorbed by gases in the atmosphere. The energy from this absorbed terrestrial radiation warms the Earth's surface and atmosphere, creating what is known as the "natural greenhouse effect." Without the natural heat-trapping properties of

these atmospheric gases, the average surface temperature of the Earth would be about 34°C lower (IPCC 1996).

Under the UNFCCC, the definition of climate change is "a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods."⁸ Given that definition, in its 1995 assessment of the science of climate change, the IPCC concluded that:

Human activities are changing the atmospheric concentrations and distributions of greenhouse gases and aerosols. These changes can produce a radiative forcing by changing either the reflection or absorption of solar radiation, or the emission and absorption of terrestrial radiation (IPCC 1996).

The IPCC went on to report in its assessment that the "[g]lobal mean surface temperature [of the Earth] has increased by between about 0.3 and 0.6 °C since the late 19th century..." (IPCC 1996) and finally concluded with the following statement:

Our ability to quantify the human influence on global climate is currently limited because the expected signal is still emerging from the noise of natural variability, and because there are uncertainties in key factors. These include the magnitude and patterns of long term natural variability and the time-evolving pattern of forcing by, and response to, changes in concentrations of greenhouse gases and aerosols, and land surface changes. Nevertheless, the balance of the evidence suggests that there is a discernable human influence on global climate (IPCC 1996).

Greenhouse Gases

Although the Earth's atmosphere consists mainly of oxygen and nitrogen, neither plays a significant role in enhancing the greenhouse effect because both are essentially transparent to terrestrial radiation. The greenhouse

⁶ The Earth's climate system comprises the atmosphere, oceans, biosphere, cryosphere, and geosphere.

⁷ For example, eccentricity, precession, and inclination.

⁸ Article 1 of the Framework Convention on Climate Change published by the UNEP/WMO Information Unit on Climate Change. (UNEP/WMO 2000)

effect is primarily a function of the concentration of water vapor, carbon dioxide, and other trace gases in the atmosphere that absorb the terrestrial radiation leaving the surface of the Earth (IPCC 1996). Changes in the atmospheric concentrations of these greenhouse gases can alter the balance of energy transfers between the atmosphere, space, land, and the oceans. A gauge of these changes is called radiative forcing, which is a simple measure of changes in the energy available to the Earth-atmosphere system (IPCC 1996). Holding everything else constant, increases in greenhouse gas concentrations in the atmosphere will produce positive radiative forcing (i.e., a net increase in the absorption of energy by the Earth).

Climate change can be driven by changes in the atmospheric concentrations of a number of radiatively active gases and aerosols. We have clear evidence that human activities have affected concentrations, distributions and life cycles of these gases (IPCC 1996).

Naturally occurring greenhouse gases include water vapor, carbon dioxide (CO₂), methane (CH₄), nitrous oxide (N₂O), and ozone (O₃). Several classes of halogenated substances that contain fluorine, chlorine, or bromine are also greenhouse gases, but they are, for the most part, emitted solely by human activities. Chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs) are halocarbons that contain chlorine, while halocarbons that contain bromine are referred to as halons. Other fluorine containing halogenated substances include hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF₆). There are also several gases that, although they do not have a direct radiative forcing effect, do influence the formation and destruction of ozone, which does have such a terrestrial radiation absorbing effect. These gases—referred to here as ozone precursors—include carbon monoxide (CO), oxides of nitrogen (NO_x), and nonmethane volatile organic compounds (NMVOCs).⁹ Aerosols—extremely small particles or liquid droplets often produced by emissions of sulfur dioxide (SO₂) and other pollutants—can also affect the absorptive characteristics of the atmosphere.

Carbon dioxide, methane, and nitrous oxide are continuously emitted to and removed from the atmosphere by natural processes on Earth. Anthropogenic activities, however, can cause additional quantities of these and other greenhouse gases to be emitted or sequestered, thereby changing their global average atmospheric concentrations. Natural activities such as respiration by plants or animals and seasonal cycles of plant growth and decay are examples of processes that only cycle carbon or nitrogen between the atmosphere and organic biomass. Such processes—except when directly or indirectly perturbed out of equilibrium by anthropogenic activities—generally do not alter average atmospheric greenhouse gas concentrations over decadal timeframes. Climatic changes resulting from anthropogenic activities, however, could have positive or negative feedback effects on these natural systems.

A brief description of each greenhouse gas, its sources, and its role in the atmosphere is given below. The following section then explains the concept of Global Warming Potentials (GWPs), which are assigned to individual gases as a measure of their relative average global radiative forcing effect.

Water Vapor (H₂O). Overall, the most abundant and dominant greenhouse gas in the atmosphere is water vapor. Water vapor is neither long-lived nor well mixed in the atmosphere, varying spatially from 0 to 2 percent (IPCC 1996). In addition, atmospheric water can exist in several physical states including gaseous, liquid, and solid. Human activities are not believed to directly affect the average global concentration of water vapor; however, the radiative forcing produced by the increased concentrations of other greenhouse gases may indirectly affect the hydrologic cycle. A warmer atmosphere has an increased water holding capacity; yet, increased concentrations of water vapor affects the formation of clouds, which can both absorb and reflect solar and terrestrial radiation. Aircraft contrails, which consist of water vapor and other aircraft emittants, are similar to clouds in their radiative forcing effects (IPCC 1999).

⁹ Also referred to in the U.S. Clean Air Act as “criteria pollutants.”

Carbon Dioxide (CO₂). In nature, carbon is cycled between various atmospheric, oceanic, land biotic, marine biotic, and mineral reservoirs. The largest fluxes occur between the atmosphere and terrestrial biota, and between the atmosphere and surface water of the oceans. In the atmosphere, carbon predominantly exists in its oxidized form as CO₂. Atmospheric carbon dioxide is part of this global carbon cycle, and therefore its fate is a complex function of geochemical and biological processes. Carbon dioxide concentrations in the atmosphere, as of 1994, increased from approximately 280 parts per million by volume (ppmv) in pre-industrial¹⁰ times to 358 ppmv, a 28 percent increase (IPCC 1996).¹¹ The IPCC has stated that “[t]here is no doubt that this increase is largely due to human activities, in particular fossil fuel combustion...” (IPCC 1996). Forest clearing, other biomass burning, and some non-energy production processes (e.g., cement production) also emit notable quantities of carbon dioxide.

In its scientific assessment, the IPCC also stated that “[t]he increased amount of carbon dioxide [in the atmosphere] is leading to climate change and will produce, on average, a global warming of the Earth’s surface because of its enhanced greenhouse effect—although the magnitude and significance of the effects are not fully resolved” (IPCC 1996).

Methane (CH₄). Methane is primarily produced through anaerobic decomposition of organic matter in biological systems. Agricultural processes such as wetland rice cultivation, enteric fermentation in animals, and the decomposition of animal wastes emit CH₄, as does the decomposition of municipal solid wastes. Methane is also emitted during the production and distribution of natural gas and petroleum, and is released as a by-product of coal mining and incomplete fossil fuel combustion.

The average global concentration of methane in the atmosphere was 1,720 parts per billion by volume (ppbv) in 1994, a 145 percent increase from the pre-industrial concentration of 700 ppbv (IPCC 1996). It is estimated that 60 to 80 percent of current CH₄ emissions are the result of anthropogenic activities. Carbon isotope measurements indicate that roughly 20 percent of methane emissions are from fossil fuel consumption, and an equal percentage is produced by natural wetlands, which will likely increase with rising temperatures and rising microbial action (IPCC 1996).

Methane is removed from the atmosphere by reacting with the hydroxyl radical (OH) and is ultimately converted to CO₂. Increasing emissions of methane, though, reduces the concentration of OH, and thereby the rate of further methane removal (IPCC 1996).

Nitrous Oxide (N₂O). Anthropogenic sources of N₂O emissions include agricultural soils, especially the use of synthetic and manure fertilizers; fossil fuel combustion, especially from mobile combustion; adipic (nylon) and nitric acid production; wastewater treatment and waste combustion; and biomass burning. The atmospheric concentration of nitrous oxide (N₂O) in 1994 was about 312 parts per billion by volume (ppbv), while pre-industrial concentrations were roughly 275 ppbv. The majority of this 13 percent increase has occurred after the pre-industrial period and is most likely due to anthropogenic activities (IPCC 1996). Nitrous oxide is removed from the atmosphere primarily by the photolytic action of sunlight in the stratosphere.

Ozone (O₃). Ozone is present in both the upper stratosphere,¹² where it shields the Earth from harmful levels of ultraviolet radiation, and at lower concentrations in the troposphere,¹³ where it is the main compo-

¹⁰ The pre-industrial period is considered as the time preceding the year 1750 (IPCC 1996).

¹¹ Carbon dioxide concentrations during the last 1,000 years of the pre-industrial period (i.e., 750-1750), a time of relative climate stability, fluctuated by about ±10 ppmv around 280 ppmv (IPCC 1996).

¹² The stratosphere is the layer from the troposphere up to roughly 50 kilometers. In the lower regions the temperature is nearly constant but in the upper layer the temperature increases rapidly because of sunlight absorption by the ozone layer. The ozone layer is the part of the stratosphere from 19 kilometers up to 48 kilometers where the concentration of ozone reaches up to 10 parts per million.

¹³ The troposphere is the layer from the ground up to 11 kilometers near the poles and up to 16 kilometers in equatorial regions (i.e., the lowest layer of the atmosphere where people live). It contains roughly 80 percent of the mass of all gases in the atmosphere and is the site for most weather processes, including most of the water vapor and clouds.

nent of anthropogenic photochemical “smog.” During the last two decades, emissions of anthropogenic chlorine and bromine-containing halocarbons, such as chlorofluorocarbons (CFCs), have depleted stratospheric ozone concentrations. This loss of ozone in the stratosphere has resulted in negative radiative forcing, representing an indirect effect of anthropogenic emissions of chlorine and bromine compounds (IPCC 1996).

Tropospheric ozone, which is also a greenhouse gas, is produced from the oxidation of methane and from reactions with precursor gases such as carbon monoxide (CO), nitrogen oxides (NO_x), and non-methane volatile organic compounds (NMVOCs). This latter group of ozone precursors is included in the category referred to as “criteria pollutants” in the United States under the Clean Air Act¹⁴ and its subsequent amendments. The tropospheric concentrations of both ozone and these precursor gases are short-lived and, therefore, spatially variable.

Halocarbons, Perfluorocarbons, and Sulfur Hexafluoride (SF₆). Halocarbons are, for the most part, man-made chemicals that have both direct and indirect radiative forcing effects. Halocarbons that contain chlorine—chlorofluorocarbons (CFCs), hydrochlorofluorocarbons (HCFCs), methyl chloroform, and carbon tetrachloride—and bromine—halons, methyl bromide, and hydrobromofluorocarbons (HBFCs)—result in stratospheric ozone depletion and are therefore controlled under the *Montreal Protocol on Substances that Deplete the Ozone Layer*. Although CFCs and HCFCs include potent global warming gases, their net radiative forcing effect on the atmosphere is reduced because they cause stratospheric ozone depletion, which is itself, an important greenhouse gas in addition to shielding the Earth from harmful levels of ultraviolet radiation. Under the *Montreal Protocol*, the United States phased out the production and importation of halons by 1994 and of CFCs

by 1996. Under the Copenhagen Amendments to the *Protocol*, a cap was placed on the production and importation of HCFCs by non-Article 5¹⁵ countries beginning in 1996, and then followed by a complete phase-out by the year 2030. The ozone depleting gases covered under the *Montreal Protocol* and its Amendments are not covered by the UNFCCC; however, they are reported in this inventory under Annex O.

Hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF₆) are not ozone depleting substances, and therefore are not covered under the *Montreal Protocol*. They are, however, powerful greenhouse gases. HFCs—primarily used as replacements for ozone depleting substances but also emitted as a by-product of the HCFC-22 manufacturing process—currently have a small aggregate radiative forcing impact; however, it is anticipated that their contribution to overall radiative forcing will increase (IPCC 1996). PFCs and SF₆ are predominantly emitted from various industrial processes including aluminum smelting, semiconductor manufacturing, electric power transmission and distribution, and magnesium casting. Currently, the radiative forcing impact of PFCs and SF₆ is also small; however, because they have extremely long atmospheric lifetimes, their concentrations tend to irreversibly accumulate in the atmosphere.

Carbon Monoxide (CO). Carbon monoxide has an indirect radiative forcing effect by elevating concentrations of CH₄ and tropospheric ozone through chemical reactions with other atmospheric constituents (e.g., the hydroxyl radical, OH) that would otherwise assist in destroying CH₄ and tropospheric ozone. Carbon monoxide is created when carbon-containing fuels are burned incompletely. Through natural processes in the atmosphere, it is eventually oxidized to CO₂. Carbon monoxide concentrations are both short-lived in the atmosphere and spatially variable.

¹⁴ [42 U.S.C § 7408, CAA § 108]

¹⁵ Article 5 of the *Montreal Protocol* covers several groups of countries, especially developing countries, with low consumption rates of ozone depleting substances. Developing countries with per capita consumption of less than 0.3 kg of certain ozone depleting substances (weighted by their ozone depleting potential) receive financial assistance and a grace period of ten additional years in the phase-out of ozone depleting substances.

Nitrogen Oxides (NO_x). The primary climate change effects of nitrogen oxides (i.e., NO and NO₂) are indirect and result from their role in promoting the formation of ozone in the troposphere and, to a lesser degree, lower stratosphere, where it has positive radiative forcing effects.¹⁶ Additionally, NO_x emissions from aircraft are also likely to decrease methane concentrations, thus having a negative radiative forcing effect (IPCC 1999). Nitrogen oxides are created from lightning, soil microbial activity, biomass burning—both natural and anthropogenic fires—fuel combustion, and, in the stratosphere, from the photodegradation of nitrous oxide (N₂O). Concentrations of NO_x are both relatively short-lived in the atmosphere and spatially variable.

Nonmethane Volatile Organic Compounds (NMVOCs). Nonmethane volatile organic compounds include compounds such as propane, butane, and ethane. These compounds participate, along with NO_x, in the formation of tropospheric ozone and other photochemical oxidants. NMVOCs are emitted primarily from transportation and industrial processes, as well as biomass burning and non-industrial consumption of organic solvents. Concentrations of NMVOCs tend to be both short-lived in the atmosphere and spatially variable.

Aerosols. Aerosols are extremely small particles or liquid droplets found in the atmosphere. They can be produced by natural events such as dust storms and volcanic activity or by anthropogenic processes such as fuel combustion. Their effect upon radiative forcing is to both absorb radiation and to alter cloud formation, thereby affecting the reflectivity (i.e., albedo) of the Earth. Aerosols are removed from the atmosphere primarily by precipitation, and generally have short atmospheric lifetimes. Like ozone precursors, aerosol concentrations and composition vary by region (IPCC 1996).

Anthropogenic aerosols in the troposphere are primarily the result of sulfur dioxide (SO₂)¹⁷ emissions from fossil fuel and biomass burning. The net effect of aero-

sols is to produce a negative radiative forcing effect (i.e., net cooling effect on the climate), although because they are short-lived in the atmosphere—lasting days to weeks—their concentrations respond rapidly to changes in emissions.¹⁸ Locally, the negative radiative forcing effects of aerosols can offset the positive forcing of greenhouse gases (IPCC 1996). “However, the aerosol effects do not cancel the global-scale effects of the much longer-lived greenhouse gases, and significant climate changes can still result” (IPCC 1996). Emission estimates for sulfur dioxide are provided in Annex P of this report.

Additionally, current research indicates that another constituent of aerosols, elemental carbon, may have a positive radiative forcing, second to only carbon dioxide, throughout the entire atmosphere (Jacobson 2001). Thus, it is possible that the net radiative forcing from aerosols may be slightly positive, but is in any event very uncertain. The large emission sources of elemental carbon include diesel exhaust, coal combustion, and biomass burning.

Global Warming Potentials

A Global Warming Potential (GWP) is intended as a quantified measure of the globally averaged relative radiative forcing impacts of a particular greenhouse gas (see Table 1-1). It is defined as the cumulative radiative forcing—both direct and indirect effects—over a specified time horizon resulting from the emission of a unit mass of gas relative to some reference gas (IPCC 1996). Direct effects occur when the gas itself is a greenhouse gas. Indirect radiative forcing occurs when chemical transformations involving the original gas produce a gas or gases that are greenhouse gases, or when a gas influences the atmospheric lifetimes of other gases. The reference gas used is CO₂, and therefore GWP weighted emissions are measured in teragrams of CO₂ equivalents (Tg CO₂ Eq.)¹⁹ The relationship between gigagrams (Gg) of a gas and Tg CO₂ Eq. can be expressed as follows:

¹⁶ NO_x emissions injected higher in the stratosphere, primarily from fuel combustion emissions from high altitude supersonic aircraft, can lead to stratospheric ozone depletion.

¹⁷ Sulfur dioxide is a primary anthropogenic contributor to the formation of “acid rain” and other forms of atmospheric acid deposition.

¹⁸ Volcanic activity can inject significant quantities of aerosol producing sulfur dioxide and other sulfur compounds into the stratosphere, which can result in a longer negative forcing effect (i.e., a few years) (IPCC 1996).

¹⁹ Carbon comprises 12/44^{ths} of carbon dioxide by weight.

Table 1-1: Global Warming Potentials and Atmospheric Lifetimes (Years)

Gas	Atmospheric Lifetime	GWP ^a
Carbon dioxide (CO ₂)	50-200	1
Methane (CH ₄) ^b	12±3	21
Nitrous oxide (N ₂ O)	120	310
HFC-23	264	11,700
HFC-125	32.6	2,800
HFC-134a	14.6	1,300
HFC-143a	48.3	3,800
HFC-152a	1.5	140
HFC-227ea	36.5	2,900
HFC-236fa	209	6,300
HFC-4310mee	17.1	1,300
CF ₄	50,000	6,500
C ₂ F ₆	10,000	9,200
C ₄ F ₁₀	2,600	7,000
C ₆ F ₁₄	3,200	7,400
SF ₆	3,200	23,900

Source: (IPCC 1996)

^a 100 year time horizon

^b The methane GWP includes the direct effects and those indirect effects due to the production of tropospheric ozone and stratospheric water vapor. The indirect effect due to the production of CO₂ is not included.

$$\text{Tg CO}_2 \text{ Eq} = (\text{Gg of gas}) \times (\text{GWP}) \times \left(\frac{\text{Tg}}{1,000 \text{ Gg}} \right)$$

where,

Tg CO₂ Eq. = Teragrams of Carbon Dioxide Equivalents

Gg = Gigagrams (equivalent to a thousand metric tons)

GWP = Global Warming Potential

Tg = Teragrams

GWP values allow policy makers to compare the impacts of emissions and reductions of different gases. According to the IPCC, GWPs typically have an uncertainty of ±35 percent. The parties to the UNFCCC have also agreed to use GWPs based upon a 100 year time horizon although other time horizon values are available.

In addition to communicating emissions in units of mass, Parties may choose also to use global warming potentials (GWPs) to reflect their inventories and projections in carbon dioxide-equivalent terms, using information provided by the Intergovernmental Panel on Climate Change (IPCC) in its Second Assessment Report. Any use of GWPs should be based on the effects of the greenhouse gases over a 100-year

Box 1-1: Emission Reporting Nomenclature

The Global Warming Potential (GWP) weighted emissions of all direct greenhouse gases presented throughout this report are presented in terms of equivalent emissions of carbon dioxide (CO₂), using units of teragrams of carbon dioxide equivalents (Tg CO₂ Eq.) In previous year's inventories emissions were reported in terms of carbon—versus carbon dioxide—equivalent emissions, using units of million metric tons of carbon equivalents (MMTCE). This change of units for reporting was implemented so that the U.S. Inventory would be more consistent with international practices, which are to report emissions in carbon dioxide equivalent units.

In order to convert the emission estimates presented in this report to those provided previously, the following equation can be employed:

$$\text{Tg CO}_2 \text{ Eq.} = \text{MMTCE} \times (44/12)$$

There are two elements to the conversion. The first element is simply nomenclature, since one teragram is equal to one million metric tons:

$$\text{Tg} = 10^9 \text{ kg} = 10^6 \text{ metric tons} = 1 \text{ megaton} = 1 \text{ million metric tons}$$

The second element is the conversion, by weight, from carbon to carbon dioxide. The molecular weight of carbon is 12, and the molecular weight of oxygen is 16; therefore, the molecular weight of CO₂ is 44 (i.e., 12 + [16×2]), as compared to 12 for carbon alone. Thus, carbon comprises 12/44ths of carbon dioxide by weight.

time horizon. In addition, Parties may also use other time horizons.²⁰

Greenhouse gases with relatively long atmospheric lifetimes (e.g., CO₂, CH₄, N₂O, HFCs, PFCs, and SF₆) tend to be evenly distributed throughout the atmosphere, and consequently global average concentrations can be determined. The short-lived gases such as water vapor, tropospheric ozone, ozone precursors (e.g., NO_x, CO, and NMVOCs), and tropospheric aerosols (e.g., SO₂ products), however, vary regionally, and consequently it is difficult to quantify their global radiative forcing impacts. No GWP values are attributed to these gases that are short-lived and spatially inhomogeneous in the atmosphere. Other greenhouse gases not yet listed by the Intergovernmental Panel on Climate Change (IPCC), but are already or soon will be in commercial use include: HFC-245fa, hydrofluoroethers (HFEs), and nitrogen trifluoride (NF₃).

Recent Trends in U.S. Greenhouse Gas Emissions

Total U.S. greenhouse gas emissions rose in 1999 to 6,746.1 teragrams of carbon dioxide equivalents (Tg CO₂ Eq.)²¹ (11.7 percent above 1990 baseline levels). The single year increase in emissions from 1998 to 1999 was 0.9 percent (59.2 Tg CO₂ Eq.), less than the 1.2 percent average annual rate of increase for the 1990s. The lower than average increase in emissions, especially given the robust economic growth in 1999, was primarily attributable to the following factors: 1) warmer than normal summer and winter conditions; 2) significantly increased output from existing nuclear power plants; and 3) reduced CH₄ emissions from coal mines and HFC-23 by-product emissions from the chemical manufacture of HCFC-22. Figure 1-1 through Figure 1-3 illustrate the overall trends in total U.S. emissions by gas, annual changes, and absolute changes since 1990.

Figure 1-1

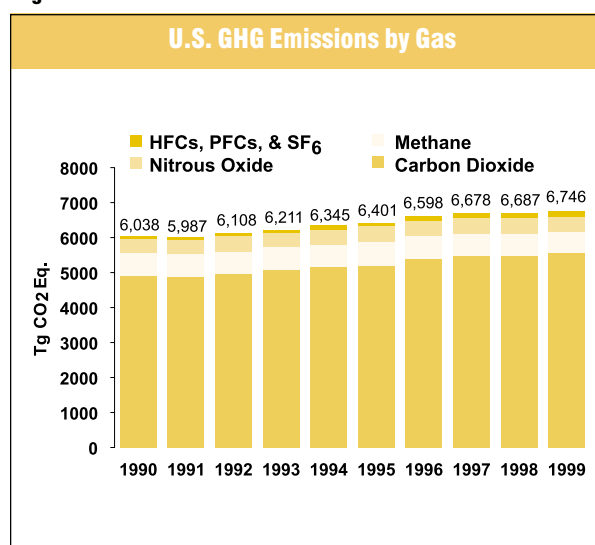
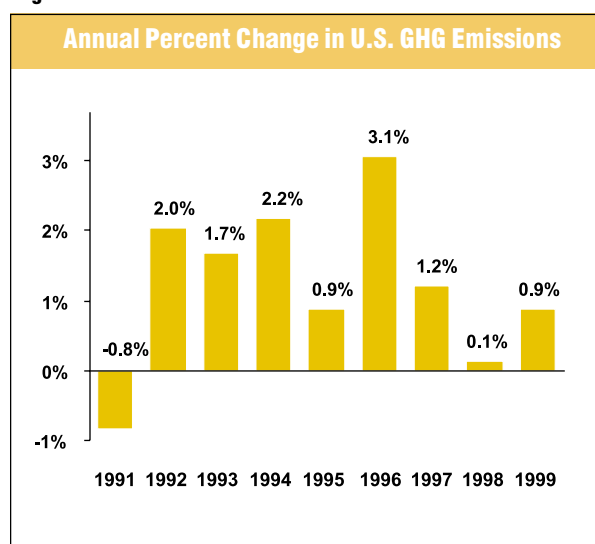


Figure 1-2

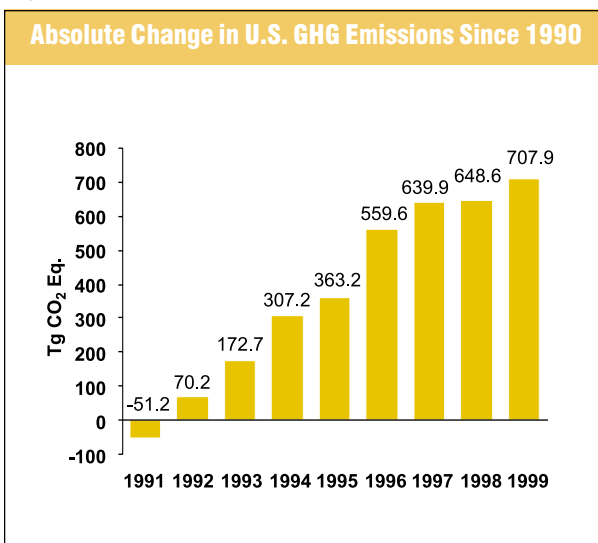


As the largest source of U.S. greenhouse gas emissions, CO₂ from fossil fuel combustion accounted for a nearly constant 80 percent of global warming potential (GWP) weighted emissions in the 1990s.²² Emissions from this source category grew by 13 percent (617.4 Tg CO₂

²⁰ Framework Convention on Climate Change; FCCC/CP/1996/15/Add.1; 29 October 1996; Report of the Conference of the Parties at its second session; held at Geneva from 8 to 19 July 1996; Addendum; Part Two: Action taken by the Conference of the Parties at its second session; Decision 9/CP.2; Communications from Parties included in Annex I to the Convention: guidelines, schedule and process for consideration; Annex: Revised Guidelines for the Preparation of National Communications by Parties Included in Annex I to the Convention; p. 18. FCCC (1996).

²¹ Estimates are presented in units of teragrams of carbon dioxide equivalents (Tg CO₂ Eq.), which weights each gas by its Global Warming Potential, or GWP (see previous section) and is consistent with international practices.

Figure 1-3



Eq.) from 1990 to 1999 and were responsible for the majority of the increase in national emissions during this period. The annual increase in CO₂ emissions from fossil fuel combustion was 1.2 percent in 1999, a figure close to the source's average annual rate of 1.4 percent during the 1990s. Historically, changes in emissions from fossil fuel combustion have been the dominant factor affecting U.S. emission trends.

Changes in CO₂ emissions from fossil fuel combustion are influenced by many long-term and short-term factors, including population and economic growth, energy price fluctuations, technological changes, and seasonal temperatures. On an annual basis, the overall demand for fossil fuels in the United States and other countries generally fluctuates in response to changes in general economic conditions, energy prices, weather, and the availability of non-fossil alternatives. For example, a year with increased consumption of goods and services, low fuel prices, severe summer and winter weather conditions, nuclear plant closures, and lower precipitation feeding hydroelectric dams would be expected to have proportionally greater fossil fuel consumption than a year with poor economic performance, high fuel prices, mild temperatures, and increased output from nuclear and hydroelectric plants.

Longer-term changes in energy consumption patterns, however, tend to be more a function of changes that affect the scale of consumption (e.g., population, number of cars, and size of houses), the efficiency with which energy is used in equipment (e.g., cars, power plants, steel mills, and light bulbs) and consumer behavior (e.g., walking, bicycling, or telecommuting to work instead of driving).

Energy-related CO₂ emissions are also a function of the type fuel or energy consumed and its carbon intensity. Producing heat or electricity using natural gas instead of coal, for example, can reduce the CO₂ emissions associated with energy consumption because of the lower carbon content of natural gas power unit of useful energy produced. Table 1-2 shows annual changes in emissions during the last few years of the 1990s for particular fuel types and sectors.

Carbon dioxide emissions from fossil fuel combustion grew rapidly in 1996, due primarily to two factors: 1) fuel switching by electric utilities from natural gas to more carbon intensive coal as colder winter conditions and the associated rise in demand for natural gas from residential, commercial and industrial customers for heating caused gas prices to rise sharply; and 2) higher consumption of petroleum fuels for transportation. Milder weather conditions in summer and winter moderated the growth in emissions in 1997; however, the shut-down of several nuclear power plants lead electric utilities to increase their consumption of coal and other fuels to offset the lost capacity. In 1998, weather conditions were again a dominant factor in slowing the growth in emissions. Warm winter temperatures resulted in a significant drop in residential, commercial, and industrial natural gas consumption. This drop in emissions from natural gas used for heating was primarily offset by two factors: 1) electric utility emissions, which increased in part due to a hot summer and its associated air conditioning demand; and 2) increased motor gasoline consumption for transportation.

²² If a full accounting of emissions from fossil fuel combustion is made by including emissions from the combustion of international bunker fuels and CH₄ and N₂O emissions associated with fuel combustion, then this percentage increases to approximately 82 percent during the 1990s.

Table 1-2: Annual Change in CO₂ Emissions from Fossil Fuel Combustion for Selected Fuels and Sectors (Tg CO₂ Eq. and Percent)

Sector	Fuel Type	1995 to 1996		1996 to 1997		1997 to 1998		1998 to 1999	
Electric Utility	Coal	89.9	5.7%	52.0	3.1%	14.3	0.8%	-32.1	-1.8%
Electric Utility	Natural Gas	-25.3	-14.7%	13.1	9.0%	16.2	10.1%	-7.8	-4.4%
Electric Utility	Petroleum	5.1	10.0%	8.1	14.4%	26.7	41.6%	-17.4	-19.1%
Transportation ^a	Petroleum	38.8	2.5%	7.6	0.5%	34.1	2.1%	57.6	3.6%
Residential	Natural Gas	21.4	8.1%	-14.0	-4.9%	-24.0	-8.9%	8.5	3.4%
Commercial	Natural Gas	7.0	4.3%	3.1	1.8%	-11.1	-6.4%	2.9	1.8%
Industrial	Coal	-7.3	-2.7%	2.0	0.8%	-1.1	-0.4%	29.2	11.2%
Industrial	Natural Gas	17.8	3.4%	-0.5	-0.1%	-14.5	-2.7%	1.6	0.3%
All Sectors^b	All Fuels^b	181.7	3.5%	71.9	1.4%	11.9	0.2%	66.4	1.2%

^a Excludes emissions from International Bunker Fuels.

^b Includes fuels and sectors not shown in table.

In 1999, the increase in emissions from fossil fuel combustion was driven largely by growth in petroleum consumption for transportation. In addition, heating fuel demand partially recovered in the residential, commercial and industrial sectors as winter temperatures dropped relative to 1998, although temperatures were still warmer than normal. These increases were offset, in part, by a decline in emissions from electric utilities due primarily to: 1) an increase in net generation of electricity by nuclear plants (8 percent) to record levels, which reduced demand from fossil fuel plants; and 2) moderated summer temperatures compared to the previous year—thereby reducing electricity demand for air conditioning. Utilization of existing nuclear power plants, measured as a plant's capacity factor,²³ has increased from just over 70 percent in 1990 to over 85 percent in 1999.

Another factor that does not affect total emissions, but does affect the interpretation of emission trends is the allocation of emissions from nonutility power producers. The Energy Information Administration (EIA) currently includes fuel consumption by nonutilities with the industrial end-use sector. In 1999, there was a large shift in generating capacity from utilities to nonutilities, as restructuring legislation spurred the sale of 7 percent

of utility generating capability (EIA 2000b). This shift is illustrated by the increase in industrial end-use sector emissions from coal and the associated decrease in electric utility emissions. However, emissions from the industrial end-use sector did not increase as much as would be expected even though net generation by nonutilities increased from 11 to 15 percent of total U.S. electricity production (EIA 2000b).²⁴

Other notable trends in emissions from additional source categories over the nine-year period from 1990 through 1999 included the following:

- Aggregate HFC and PFC emissions resulting from the substitution of ozone depleting substances (e.g., CFCs) increased by 55.8 Tg CO₂ Eq. This increase was partly offset, however, by reductions in PFC emissions from aluminum production (9.2 Tg CO₂ Eq. or 48 percent), and reductions in emissions of HFC-23 from the production of HCFC-22 (4.4 Tg CO₂ Eq. or 13 percent). Reductions in PFC emissions from aluminum production were the result of both voluntary industry emission reduction efforts and lower domestic aluminum production. HFC-23 emissions from the production of HCFC-22 decreased due to a reduction in the intensity of emissions from that

²³ The capacity factor is defined as the ratio of the electrical energy produced by a generating unit for a given period of time to the electrical energy that could have been produced at continuous full-power operation during the same period (EIA 1999).

²⁴ It is unclear whether reporting problems for electric utilities and the industrial end-use sector have increased with the dramatic growth in nonutilities and the opening of the electric power industry to increased competition.

Box 1-2: Recent Trends in Various U.S. Greenhouse Gas Emissions-Related Data

There are several ways to assess a nation's greenhouse gas emitting intensity. The basis for measures of intensity can be 1) per unit of aggregate energy consumption, because energy-related activities are the largest sources of emissions; 2) per unit of fossil fuel consumption, because almost all energy-related emissions involve the combustion of fossil fuels; 3) per unit of electricity consumption, because the electric power industry—utilities and nonutilities combined—were the largest sources of U.S. greenhouse gas emissions in 1999; 4) per unit of total gross domestic product as a measure of national economic activity; or 5) on a per capita basis. Depending upon the measure used, the United States could appear to have reduced or increased its national greenhouse gas intensity during the 1990s.

Table 1-3 provides data on various statistics related to U.S. greenhouse gas emissions normalized to 1990 as a baseline year. Greenhouse gas emissions in the U.S. have grown at an average annual rate of 1.2 percent since 1990. This rate is slightly slower than that for total energy or fossil fuel consumption—thereby indicating an improved or lower greenhouse gas emitting intensity—and much slower than that for either electricity consumption or overall gross domestic product. Emissions, however, are growing faster than national population, thereby indicating a worsening or higher greenhouse gas emitting intensity on a per capita basis (see Figure 1-4). Overall, atmospheric CO₂ concentrations—a function of many complex anthropogenic and natural processes—are increasing at 0.4 percent per year.

Table 1-3: Recent Trends in Various U.S. Data (Index 1990 = 100)

Variable	1991	1992	1993	1994	1995	1996	1997	1998	1999	Growth Rate ^f
GHG Emissions ^a	99	101	103	105	106	109	111	111	112	1.2%
Energy Consumption ^b	100	101	104	106	108	111	112	112	115	1.5%
Fossil Fuel Consumption ^b	99	101	103	106	107	110	112	112	113	1.4%
Electricity Consumption ^b	102	102	105	108	111	114	116	119	120	2.1%
GDP ^c	100	103	105	110	112	116	122	127	132	3.2%
Population ^d	101	102	103	104	105	106	107	108	109	1.0%
Atmospheric CO ₂ Concentration ^e	100	101	101	101	102	102	103	104	104	0.4%

^a GWP weighted values

^b Energy content weighted values (EIA 2000a)

^c Gross Domestic Product in chained 1996 dollars (BEA 2000)

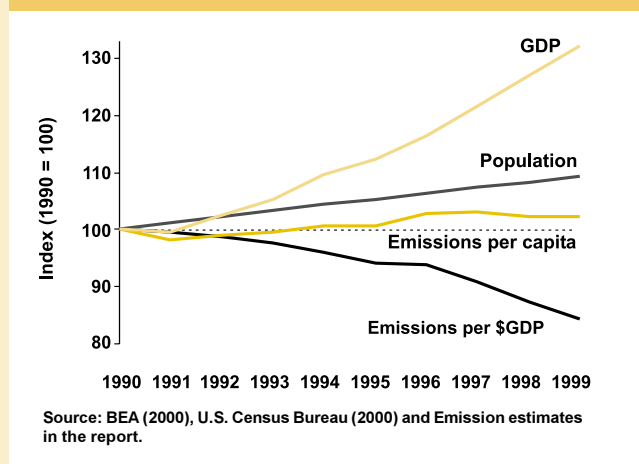
^d (U.S. Census Bureau 2000)

^e Mauna Loa Observatory, Hawaii (Keeling and Whorf 2000)

^f Average annual growth rate

Figure 1-4

U.S. Greenhouse Gas Emissions Per Capita and Per Dollar of Gross Domestic Product



source, despite increased HCFC-22 production.

- Emissions of N₂O from mobile combustion rose by 9.1 Tg CO₂ Eq. (17 percent), primarily due to increased rates of N₂O generation in highway vehicles.
- Methane emissions from coal mining dropped by 26.0 Tg CO₂ Eq. (30 percent) as a result of the mining of less gassy coal from underground mines and the increased use of methane from degasification systems.
- Nitrous oxide emissions from agricultural soil management increased by 29.3 Tg CO₂ Eq. (11 percent) as fertilizer consumption, livestock populations, and crop production rose.
- By 1998, all of the three major adipic acid producing plants had voluntarily implemented N₂O abatement technology, and as a result, emissions fell by 9.3 Tg CO₂ Eq. (51 percent). The majority of this decline occurred from 1997 to 1998, despite increased production.

Overall, from 1990 to 1999, total emissions of CO₂ and N₂O increased by 645.2 (13 percent) and 35.7 Tg CO₂ Eq. (9 percent), respectively, while CH₄ emissions decreased by 24.9 Tg CO₂ Eq. (4 percent). During the same period, aggregate weighted emissions of HFCs, PFCs, and SF₆ rose by 51.8 Tg CO₂ Eq. (62 percent). Despite being emitted in smaller quantities relative to the other principle greenhouse gases, emissions of HFCs, PFCs, and SF₆ are significant because many of them have extremely high global warming potentials and, in the cases of PFCs and SF₆, long atmospheric lifetimes. Conversely, U.S. greenhouse gas emissions were partly offset by carbon sequestration in forests and in landfilled carbon, which were estimated to be 15 percent of total emissions in 1999.

As an alternative, emissions can be aggregated across gases by the IPCC defined sectors, referred to here as chapters. Over the ten year period of 1990 to 1999, total emissions in the Energy, Industrial Processes, Agriculture, and Waste chapters climbed by 603.6 (12 percent), 58.2 (33 percent), 38.3 (8 percent), and 7.8 Tg CO₂ Eq. (3 percent), respectively. Estimates of net carbon sequestration in the Land-Use Change and Forestry chapter declined by 69.5 Tg CO₂ Eq. (7 percent).

Table 1-4 summarizes emissions and sinks from all U.S. anthropogenic sources in weighted units of Tg CO₂ Eq., while unweighted gas emissions and sinks in gigagrams (Gg) are provided in Table 1-5. Alternatively, emissions and sinks are aggregated by chapter in Table 1-6 and Figure 1-5.

Methodology and Data Sources

Emissions of greenhouse gases from various source and sink categories have been estimated using methodologies that are consistent with the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC/UNEP/OECD/IEA 1997). To the extent possible, the present U.S. Inventory relies on published activity and emission factor data. Depending on the emission source category, activity data can include fuel consumption or deliveries, vehicle-miles traveled, raw material processed, etc.; emission factors are factors that relate quantities of emissions to an activity. For some sources, IPCC default methodologies and emission factors have been employed. However, for most emission sources, the IPCC default methodologies were expanded and more comprehensive methods were applied.

Inventory emission estimates from energy consumption and production activities are based primarily on the latest official fuel consumption data from the En-

Figure 1-5

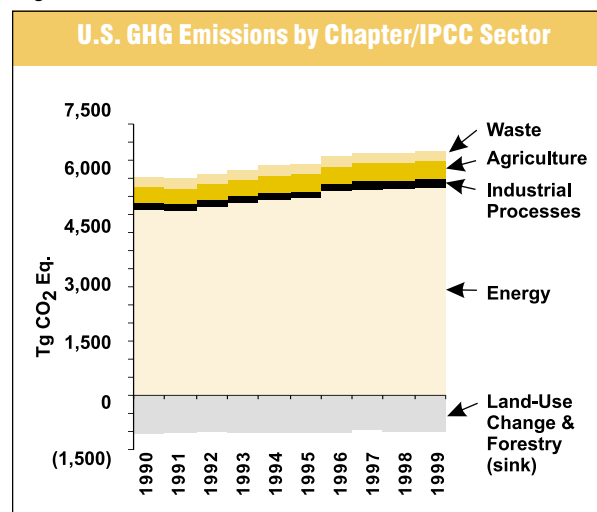


Table 1-4: Recent Trends in U.S. Greenhouse Gas Emissions and Sinks (Tg CO₂ Eq.)

Gas/Source	1990	1995	1996	1997	1998	1999
CO₂	4,913.0	5,219.8	5,403.2	5,478.7	5,489.7	5,558.1
Fossil Fuel Combustion	4,835.7	5,121.3	5,303.0	5,374.9	5,386.8	5,453.1
Cement Manufacture	33.3	36.8	37.1	38.3	39.2	39.9
Waste Combustion	17.6	23.1	24.0	25.7	25.1	26.0
Lime Manufacture	11.2	12.8	13.5	13.7	13.9	13.4
Natural Gas Flaring	5.1	13.6	13.0	12.0	10.8	11.7
Limestone and Dolomite Use	5.1	7.0	7.3	8.3	8.1	8.3
Soda Ash Manufacture and Consumption	4.1	4.3	4.3	4.4	4.3	4.2
Carbon Dioxide Consumption	0.8	1.0	1.1	1.3	1.4	1.6
Land-Use Change and Forestry (Sink) ^a	(1,059.9)	(1,019.1)	(1,021.6)	(981.9)	(983.3)	(990.4)
International Bunker Fuels ^b	114.0	101.0	102.2	109.8	112.8	107.3
CH₄	644.5	650.5	638.0	632.0	624.8	619.6
Landfills	217.3	222.9	219.1	217.8	213.6	214.6
Enteric Fermentation	129.5	136.3	132.2	129.6	127.5	127.2
Natural Gas Systems	121.2	124.2	125.8	122.7	122.1	121.8
Coal Mining	87.9	74.6	69.3	68.8	66.5	61.8
Manure Management	26.4	31.0	30.7	32.6	35.2	34.4
Petroleum Systems	27.2	24.5	24.0	24.0	23.3	21.9
Wastewater Treatment	11.2	11.8	11.9	12.0	12.1	12.2
Rice Cultivation	8.7	9.5	8.8	9.6	10.1	10.7
Stationary Combustion	8.5	8.9	9.0	8.1	7.6	8.1
Mobile Combustion	5.0	4.9	4.8	4.7	4.6	4.5
Petrochemical Production	1.2	1.5	1.6	1.6	1.6	1.7
Agricultural Residue Burning	0.5	0.5	0.6	0.6	0.6	0.6
Silicon Carbide Production	+	+	+	+	+	+
International Bunker Fuels ^b	+	+	+	+	+	+
N₂O	396.9	431.9	441.6	444.1	433.7	432.6
Agricultural Soil Management	269.0	285.4	294.6	299.8	300.3	298.3
Mobile Combustion	54.3	66.8	65.3	65.2	64.2	63.4
Nitric Acid	17.8	19.9	20.7	21.2	20.9	20.2
Manure Management	16.0	16.4	16.8	17.1	17.2	17.2
Stationary Combustion	13.6	14.3	14.9	15.0	15.1	15.7
Adipic Acid	18.3	20.3	20.8	17.1	7.3	9.0
Human Sewage	7.1	8.2	7.8	7.9	8.1	8.2
Agricultural Residue Burning	0.4	0.4	0.4	0.4	0.5	0.4
Waste Combustion	0.3	0.3	0.3	0.3	0.2	0.2
International Bunker Fuels ^b	1.0	0.9	0.9	1.0	1.0	1.0
HFCs, PFCs, and SF₆	83.9	99.0	115.1	123.3	138.6	135.7
Substitution of Ozone Depleting Substances	0.9	24.0	34.0	42.1	49.6	56.7
HCFC-22 Production	34.8	27.1	31.2	30.1	40.0	30.4
Electrical Transmission and Distribution	20.5	25.7	25.7	25.7	25.7	25.7
Aluminum Production	19.3	11.2	11.6	10.8	10.1	10.0
Semiconductor Manufacture	2.9	5.5	7.0	7.0	6.8	6.8
Magnesium Production and Processing	5.5	5.5	5.6	7.5	6.3	6.1
Total Emissions	6,038.2	6,401.3	6,597.8	6,678.1	6,686.8	6,746.1
Net Emissions (Sources and Sinks)	4,978.3	5,382.3	5,576.2	5,696.2	5,703.5	5,755.7

+ Does not exceed 0.05 Tg CO₂ Eq.

^a Sinks are only included in net emissions total, and are based partially on projected activity data.

^b Emissions from International Bunker Fuels are not included in totals.

Note: Totals may not sum due to independent rounding.

Note: Parentheses indicate negative values (or sequestration).

Table 1-5: Recent Trends in U.S. Greenhouse Gas Emissions and Sinks (Gg)

Gas/Source	1990	1995	1996	1997	1998	1999
CO₂	4,912,959	5,219,832	5,403,220	5,478,677	5,489,729	5,558,150
Fossil Fuel Combustion	4,835,688	5,121,263	5,302,961	5,374,913	5,386,762	5,453,088
Cement Manufacture	33,278	36,847	37,079	38,323	39,218	39,896
Waste Combustion	17,572	23,065	23,968	25,674	25,145	25,960
Lime Manufacture	11,238	12,805	13,495	13,685	13,914	13,426
Natural Gas Flaring	5,121	13,587	12,998	12,026	10,839	11,701
Limestone and Dolomite Use	5,117	6,987	7,305	8,327	8,114	8,290
Soda Ash Manufacture and Consumption	4,144	4,309	4,273	4,434	4,325	4,217
Carbon Dioxide Consumption	800	968	1,140	1,294	1,413	1,572
Land-Use Change and Forestry (Sink) ^a	(1,059,900)	(1,019,000)	(1,021,400)	(981,900)	(983,400)	(990,400)
International Bunker Fuels ^b	114,001	101,014	102,197	109,788	112,771	107,345
CH₄	30,689	30,978	30,379	30,096	29,754	29,504
Landfills	10,346	10,614	10,435	10,371	10,171	10,221
Enteric Fermentation	6,166	6,492	6,295	6,172	6,072	6,057
Natural Gas Systems	5,772	5,912	5,993	5,841	5,814	5,799
Coal Mining	4,184	3,550	3,301	3,274	3,168	2,944
Manure Management	1,256	1,477	1,463	1,553	1,677	1,638
Petroleum Systems	1,294	1,168	1,143	1,142	1,108	1,044
Wastewater Treatment	533	561	567	572	577	583
Rice Cultivation	414	452	419	455	481	509
Stationary Combustion	403	422	430	386	361	386
Mobile Combustion	237	232	228	225	219	215
Petrochemical Production	56	72	75	77	77	79
Agricultural Residue Burning	25	24	28	29	30	28
Silicon Carbide Production	1	1	1	1	1	1
International Bunker Fuels ^b	2	2	2	2	2	2
N₂O	1,280	1,393	1,424	1,433	1,399	1,395
Agricultural Soil Management	868	921	950	967	969	962
Mobile Combustion	175	215	211	210	207	204
Nitric Acid	58	64	67	68	67	65
Manure Management	52	53	54	55	55	55
Stationary Combustion	44	46	48	49	49	51
Adipic Acid	59	66	67	55	23	29
Human Sewage	23	27	25	26	26	26
Agricultural Residue Burning	1	1	1	1	1	1
Waste Combustion	1	1	1	1	1	1
International Bunker Fuels ^b	3	3	3	3	3	3
HFCs, PFCs, and SF₆	M	M	M	M	M	M
Substitution of Ozone Depleting Substances	M	M	M	M	M	M
HCFC-22 Production ^c	3	2	3	3	3	3
Electrical Transmission and Distribution ^d	1	1	1	1	1	1
Aluminum Production	M	M	M	M	M	M
Semiconductor Manufacture	M	M	M	M	M	M
Magnesium Production and Processing ^d	0	0	0	0	0	0
NO_x	21,955	22,755	23,663	23,934	23,613	23,042
CO	85,978	80,784	87,306	87,131	82,619	83,093
NMVOCs	18,843	18,662	17,350	17,586	16,555	16,129

M Mixture of multiple gases

^a Sinks are not included in CO₂ emissions total, and are based partially on projected activity data.

^b Emissions from International Bunker Fuels are not included in totals.

^c HFC-23 emitted

^d SF₆ emitted

Note: Totals may not sum due to independent rounding.

Note: Parentheses indicate negative values (or sequestration).

Table 1-6: Recent Trends in U.S. Greenhouse Gas Emissions and Sinks by Chapter/IPCC Sector (Tg CO₂ Eq.)

Chapter/IPCC Sector	1990	1995	1996	1997	1998	1999
Energy	5,158.4	5,452.9	5,629.1	5,695.4	5,700.9	5,762.0
Industrial Processes	175.8	202.7	221.5	229.3	235.3	234.0
Agriculture	450.5	479.5	484.1	489.8	491.4	488.8
Land-Use Change and Forestry (Sink)*	(1,059.9)	(1,019.1)	(1,021.6)	(981.9)	(983.3)	(990.4)
Waste	253.4	266.2	263.1	263.6	259.2	261.3
Total Emissions	6,038.2	6,401.3	6,597.8	6,678.1	6,686.8	6,746.1
Net Emissions (Sources and Sinks)	4,978.3	5,382.3	5,576.2	5,696.2	5,703.5	5,755.7

* Sinks are only included in net emissions total, and are based partially on projected activity data.

Note: Totals may not sum due to independent rounding.

Note: Parentheses indicate negative values (or sequestration).

Box 1-3: Greenhouse Gas Emissions from Transportation Activities

Motor vehicle usage is increasing all over the world, including in the United States. Since the 1970s, the number of highway vehicles registered in the United States has increased faster than the overall population, according to the Federal Highway Administration (FHWA). Likewise, the number of miles driven—up 13 percent from 1990 to 1999—and gallons of gasoline consumed each year in the United States have increased steadily since the 1980s, according to the FHWA and Energy Information Administration, respectively. These increases in motor vehicle usage are the result of a confluence of factors including population growth, economic growth, urban sprawl, low fuel prices, and increasing popularity of sport utility vehicles and other light-duty trucks that tend to have lower fuel efficiency.²⁵ A similar set of social and economic trends has led to a significant increase in air travel and freight transportation—by both air and road modes—during the 1990s.

One of the unintended consequences of these changes is a slowing of progress toward cleaner air in both urban and rural parts of the country. Passenger cars, trucks, motorcycles, and buses emit significant quantities of air pollutants with local, regional, and global effects. Motor vehicles are major sources of carbon monoxide (CO), carbon dioxide (CO₂), methane (CH₄), nonmethane volatile organic compounds (NMVOCs), nitrogen oxides (NO_x), nitrous oxide (N₂O), and hydrofluorocarbons (HFCs). Motor vehicles are also important contributors to many serious air pollution problems, including ground-level ozone (i.e., smog), acid rain, fine particulate matter, and global warming. Within the United States and abroad, government agencies have taken actions to reduce these emissions. Since the 1970s, the EPA has required the reduction of lead in gasoline, developed strict emission standards for new passenger cars and trucks, directed States to enact comprehensive motor vehicle emission control programs, required inspection and maintenance programs, and more recently, introduced the use of reformulated gasoline. New vehicles are now equipped with advanced emissions controls, which are designed to reduce emissions of NO_x, hydrocarbons, and CO.

Table 1-7 summarizes greenhouse gas emissions from all transportation-related activities. Overall, transportation activities—excluding international bunker fuels—accounted for an almost constant 26 percent of total U.S. greenhouse gas emissions from 1990 to 1999. These emissions were primarily CO₂ from fuel combustion, which increased by 16 percent from 1990 to 1999. However, because of larger increases in N₂O and HFC emissions during this period, overall emissions from transportation activities actually increased by 18 percent.

²⁵ The average miles per gallon achieved by the U.S. highway vehicle fleet actually decreased by slightly less than one percent in both 1998 and 1999.

Table 1-7: Transportation-Related Greenhouse Gas Emissions (Tg CO₂ Eq.)

Gas/Vehicle Type	1990	1995	1996	1997	1998	1999
CO₂	1,474.4	1,581.8	1,621.2	1,631.4	1,659.0	1,716.4
Passenger Cars	620.0	641.9	654.1	660.2	674.5	688.9
Light-Duty Trucks	283.1	325.3	333.5	337.3	356.9	364.8
Other Trucks	206.0	235.9	248.1	257.0	257.9	269.7
Buses	10.7	13.5	11.3	12.0	12.3	12.9
Aircraft ^a	176.7	171.5	180.2	179.0	183.0	184.6
Boats and Vessels	59.4	66.9	63.8	50.2	47.9	65.6
Locomotives	28.4	31.5	33.4	34.4	33.6	35.1
Other ^b	90.1	95.3	96.7	101.4	93.0	94.9
International Bunker Fuels ^c	114.0	101.0	102.2	109.8	112.8	107.3
CH₄	5.0	4.9	4.8	4.7	4.6	4.5
Passenger Cars	2.4	2.0	2.0	2.0	2.0	1.9
Light-Duty Trucks	1.6	1.9	1.6	1.6	1.5	1.4
Other Trucks and Buses	0.4	0.5	0.7	0.7	0.7	0.7
Aircraft	0.2	0.1	0.1	0.2	0.1	0.2
Boats and Vessels	0.1	0.1	0.1	0.1	0.1	0.1
Locomotives	0.1	0.1	0.1	0.1	+	+
Other ^d	0.2	0.2	0.2	0.2	0.2	0.2
International Bunker Fuels ^c	+	+	+	+	+	+
N₂O	54.3	66.8	65.3	65.2	64.2	63.4
Passenger Cars	31.0	33.0	32.7	32.4	32.1	31.5
Light-Duty Trucks	17.8	27.1	23.9	24.0	23.3	22.7
Other Trucks and Buses	2.6	3.6	5.6	5.8	5.9	6.1
Aircraft ^a	1.7	1.7	1.8	1.7	1.8	1.8
Boats and Vessels	0.4	0.5	0.4	0.3	0.3	0.4
Locomotives	0.3	0.3	0.3	0.2	0.2	0.2
Other ^d	0.6	0.6	0.6	0.6	0.6	0.6
International Bunker Fuels ^c	1.0	0.9	0.9	1.0	1.0	1.0
HFCs	+	9.5	13.5	17.2	20.6	23.7
Mobile Air Conditioners ^e	+	9.5	13.5	17.2	20.6	23.7
Total^c	1,533.7	1,663.0	1,704.8	1,718.5	1,748.4	1,808.0

+ Does not exceed 0.05 Tg CO₂ Eq.

Note: Totals may not sum due to independent rounding.

^a Aircraft emissions consist of emissions from all jet fuel (less bunker fuels) and aviation gas consumption.

^b "Other" CO₂ emissions include motorcycles, construction equipment, agricultural machinery, pipelines, and lubricants.

^c Emissions from International Bunker Fuels include emissions from both civilian and military activities, but are not included in totals.

^d "Other" CH₄ and N₂O emissions include motorcycles, construction equipment, agricultural machinery, gasoline-powered recreational, industrial, lawn and garden, light commercial, logging, airport service, other equipment; and diesel-powered recreational, industrial, lawn and garden, light construction, airport service.

^e Includes primarily HFC-134a.

Box 1-4: Greenhouse Gas Emissions from Electric Utilities

Like transportation, activities related to the generation, transmission, and distribution of electricity in the United States resulted in a significant fraction of total U.S. greenhouse gas emissions. The electric power industry in the United States is composed of traditional electric utilities as well as other entities, such as power marketers and nonutility power producers.

Table 1-8 presents emissions from electric utility-related activities. Aggregate emissions from electric utilities of all greenhouse gases increased by 11 percent from 1990 to 1999, and accounted for a relatively constant 29 percent of U.S. emissions during the same period. Emissions from nonutility generators are not included in these estimates. Nonutilities were estimated to have produced about 15 percent of the electricity generated in the United States in 1999, up from 11 percent in 1998 (EIA 2000c). Therefore a more complete accounting of greenhouse gas emissions from the electric power industry (i.e., utilities and nonutilities combined) would account for roughly 40 percent of U.S. CO₂ emissions (EIA 2000d).

The majority of electric utility-related emissions resulted from the combustion of coal in boilers to produce steam that is passed through a turbine to generate electricity. Overall, the generation of electricity—especially when nonutility generators are included—results in a larger portion of total U.S. greenhouse gas emissions than any other activity.

Table 1-8: Electric Utility-Related Greenhouse Gas Emissions (Tg CO₂ Eq.)

Gas/Fuel Type or Source	1990	1995	1996	1997	1998	1999
CO₂	1,757.3	1,810.6	1,880.3	1,953.5	2,010.7	1,953.4
Coal	1,509.3	1,587.7	1,677.7	1,729.7	1,744.0	1,711.9
Natural Gas	151.1	171.8	146.5	159.6	175.8	168.0
Petroleum	96.8	51.0	56.0	64.1	90.8	73.4
Geothermal	0.2	0.1	0.1	0.1	0.1	+
CH₄	0.5	0.5	0.5	0.5	0.5	0.5
Stationary Combustion (Utilities)	0.5	0.5	0.5	0.5	0.5	0.5
N₂O	7.4	7.8	8.2	8.5	8.7	8.6
Stationary Combustion (Utilities)	7.4	7.8	8.2	8.5	8.7	8.6
SF₆	20.5	25.7	25.7	25.7	25.7	25.7
Electrical Transmission and Distribution	20.5	25.7	25.7	25.7	25.7	25.7
Total	1,785.7	1,844.5	1,914.7	1,988.2	2,045.6	1,988.2

Note: Totals may not sum due to independent rounding.

Box 1-5: IPCC Good Practice Guidance

In response to a request by Parties to the United Nations Framework Convention on Climate Change (UNFCCC), the Intergovernmental Panel on Climate Change (IPCC) finalized a set of good practice guidance in May 2000 on uncertainty and good practices in inventory management. The report, entitled *Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories (Good Practice)*, was developed with extensive participation of experts from the United States as well as many other countries.²⁶ It focuses on providing direction to countries to produce emission estimates that are as accurate, with the least uncertainty, as possible. In addition, *Good Practice* was designed as a tool to compliment the methodologies suggested in the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC Guidelines)*.

In order to obtain these goals, *Good Practice* establishes a set of guidelines for ensuring the following standards are met:

- The most appropriate estimation method is used, within the context of the *IPCC Guidelines*
- Quality control and quality assurance measures are adhered to
- Proper assessment and documentation of data and information is carried out
- Uncertainties are quantified and tracked for each source category as well as the inventory in its entirety

By providing such direction, the IPCC hopes to help countries provide inventories that are transparent, documented, and comparable, and that have been assessed for uncertainties, checked for quality control and quality assurance, and used resources efficiently.

ergy Information Administration (EIA) of the U.S. Department of Energy. Emission estimates for NO_x, CO, and NMVOCs were taken directly, except where noted, from the United States Environmental Protection Agency's (EPA) report, *National Air Pollutant Emission Trends 1900 - 1999* (EPA 2000), which is an annual EPA publication that provides the latest estimates of regional and national emissions of criteria pollutants. Emissions of these pollutants are estimated by the EPA based on sta-

tistical information about each source category, emission factors, and control efficiencies. While the EPA's estimation methodologies for criteria pollutants are conceptually similar to the IPCC recommended methodologies, the large number of sources EPA used in developing its criteria pollutant estimates makes it difficult to reproduce the methodologies from EPA (2000) in this inventory document. In these instances, the references containing detailed documentation of the methods used are identified

²⁶ See <<http://www.ipcc-nggip.iges.or.jp/public/gp/gpgaum.htm>>

for the interested reader. For agricultural sources, the EPA criteria pollutant emission estimates were supplemented using activity data from other agencies. Complete documentation of the methodologies and data sources used is provided in conjunction with the discussion of each source and in the various annexes.

Emissions from fossil fuels combusted in civilian and military ships and aircraft engaged in the international transport of passengers and cargo are not included in U.S. totals, but are reported separately as international bunkers in accordance with IPCC reporting guidelines (IPCC/UNEP/OECD/IEA 1997). Carbon dioxide emissions from fuel combusted within U.S. territories, however, are included in U.S. totals.

Uncertainty in and Limitations of Emission Estimates

While the current U.S. emissions inventory provides a solid foundation for the development of a more detailed and comprehensive national inventory, it has several strengths and weaknesses.

First, this inventory by itself does not provide a complete picture of past or future emissions in the United States; it only provides an inventory of U.S. emissions for the years 1990 through 1999. However, the United States believes that common and consistent inventories taken over a period of time can and will contribute to understanding future emission trends. The United States produced its first comprehensive inventory of greenhouse gas emissions and sinks in 1993, and intends to update it annually, in conjunction with its commitments under the UNFCCC. The methodologies used to estimate emissions will also be updated periodically as methods and information improve and as further guidance is received from the IPCC and UNFCCC.

Secondly, there are uncertainties associated with the emission estimates. Some of the current estimates, such as those for CO₂ emissions from energy-related activities and cement processing, are considered to be fairly accurate. For some other categories of emissions, how-

ever, a lack of data or an incomplete understanding of how emissions are generated limits the scope or accuracy of the estimates presented. Despite these uncertainties, the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC/UNEP/OECD/IEA 1997) require that countries provide single point estimates for each gas and emission or removal source category. Within the discussion of each emission source, specific factors affecting the accuracy of the estimates are discussed.

Finally, while the IPCC methodologies provided in the *Revised 1996 IPCC Guidelines* represent baseline methodologies for a variety of source categories, many of these methodologies continue to be improved and refined as new research and data becomes available. The current U.S. inventory uses the IPCC methodologies when applicable, and supplements them with other available methodologies and data where possible. The United States realizes that additional efforts are still needed to improve methodologies and data collection procedures. Specific areas requiring further research include:

- *Incorporating excluded emission sources.* Quantitative estimates of some of the sources and sinks of greenhouse gas emissions are not available at this time. In particular, emissions from some land-use activities and industrial processes are not included in the inventory either because data are incomplete or because methodologies do not exist for estimating emissions from these source categories. See Annex S for a discussion of the sources of greenhouse gas emissions and sinks excluded from this report.
- *Improving the accuracy of emission factors.* Further research is needed in some cases to improve the accuracy of emission factors used to calculate emissions from a variety of sources. For example, the accuracy of current emission factors applied to methane and nitrous oxide emissions from stationary and mobile combustion is highly uncertain.
- *Collecting detailed activity data.* Although methodologies exist for estimating emissions for some sources, problems arise in obtaining activity data at

a level of detail in which aggregate emission factors can be applied. For example, the ability to estimate emissions of SF₆ from electrical transmission and distribution is limited due to a lack of activity data regarding national SF₆ consumption or average equipment leak rates.

- *Applying Global Warming Potentials.* GWP values have several limitations, including that they are not applicable to unevenly distributed gases and aerosols such as tropospheric ozone and its precursors. They are also intended to reflect global averages and, therefore, do not account for regional effects. Overall, the main uncertainties in developing GWP values are the estimation of atmospheric lifetimes, assessing indirect effects, choosing the appropriate integration time horizon, and assessing instantaneous radiative forcing effects, which are dependent upon existing atmospheric concentrations. According to the IPCC, GWPs typically have an uncertainty of ±35 percent (IPCC 1996).

Emissions calculated for the U.S. inventory reflect current best estimates; in some cases, however, estimates are based on approximate methodologies, assumptions, and incomplete data. As new information becomes available in the future, the United States will continue to improve and revise its emission estimates.

Organization of Report

In accordance with the IPCC guidelines for reporting contained in the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC/UNEP/OECD/IEA 1997), this U.S. inventory of greenhouse gas emissions and sinks is segregated into six sector-specific chapters, listed below in Table 1-9.

Within each chapter, emissions are identified by the anthropogenic activity that is the source or sink of the greenhouse gas emissions being estimated (e.g., coal mining). Overall, the following organizational structure is consistently applied throughout this report:

Chapter/IPCC Sector: Overview of emission trends for each IPCC defined sector

Source: Description of source pathway and emission trends from 1990 through 1999

- **Methodology:** Description of analytical methods employed to produce emission estimates
- **Data Sources:** Identification of data references, primarily for activity data and emission factors
- **Uncertainty:** Discussion of relevant issues related to the uncertainty in the emission estimates presented

Table 1-9: IPCC Sector Descriptions

Chapter/IPCC Sector	Activities Included
Energy	Emissions of all greenhouse gases resulting from stationary and mobile energy activities including fuel combustion and fugitive fuel emissions.
Industrial Processes	By-product or fugitive emissions of greenhouse gases from industrial processes not directly related to energy activities such as fossil fuel combustion.
Solvent Use	Emissions, of primarily non-methane volatile organic compounds (NMVOCs), resulting from the use of solvents.
Agriculture	Anthropogenic emissions from agricultural activities except fuel combustion and sewage emissions, which are addressed under Energy and Waste, respectively.
Land-Use Change and Forestry	Emissions and removals from forest and land-use change activities, primarily carbon dioxide.
Waste	Emissions from waste management activities.

Source: (IPCC/UNEP/OECD/IEA 1997)

Special attention is given to carbon dioxide from fossil fuel combustion relative to other sources because of its share of emissions relative to other sources and its dominant influence on emission trends. For example, each energy consuming end-use sector (i.e., residential, com-

mercial, industrial, and transportation), as well as the electric utility sector, is treated individually. Additional information for certain source categories and other topics is also provided in several Annexes listed in Table 1-10.

Table 1-10: List of Annexes

ANNEX A	Methodology for Estimating Emissions of CO ₂ from Fossil Fuel Combustion	ANNEX J	Methodology for Estimating CH ₄ Emissions from Enteric Fermentation
ANNEX B	Methodology for Estimating Carbon Stored in Products from Non-Energy Uses of Fossil Fuels	ANNEX K	Methodology for Estimating CH ₄ Emissions from Manure Management
ANNEX C	Methodology for Estimating Emissions of CH ₄ , N ₂ O, and Criteria Pollutants from Stationary Combustion	ANNEX L	Methodology for Estimating N ₂ O Emissions from Agricultural Soil Management
ANNEX D	Methodology for Estimating Emissions of CH ₄ , N ₂ O, and Criteria Pollutants from Mobile Combustion	ANNEX M	Methodology for Estimating CH ₄ Emissions from Landfills
ANNEX E	Methodology for Estimating CH ₄ Emissions from Coal Mining	ANNEX N	Global Warming Potential Values
ANNEX F	Methodology for Estimating CH ₄ Emissions from Natural Gas Systems	ANNEX O	Ozone Depleting Substance Emissions
ANNEX G	Methodology for Estimating CH ₄ Emissions from Petroleum Systems	ANNEX P	Sulfur Dioxide Emissions
ANNEX H	Methodology for Estimating Emissions from International Bunker Fuels Used by the U.S. Military	ANNEX Q	Complete List of Source Categories
ANNEX I	Methodology for Estimating HFC, PFC, and SF ₆ Emissions from Substitution of Ozone Depleting Substances	ANNEX R	IPCC Reference Approach for Estimating CO ₂ Emissions from Fossil Fuel Combustion
		ANNEX S	Sources of Greenhouse Gas Emissions Excluded
		ANNEX T	Constants, Units, and Conversions
		ANNEX U	Abbreviations
		ANNEX V	Chemical Symbols
		ANNEX W	Glossary